CARR

High Temperature Measurement by Electric Means

Electrical Engineer

1911

HIGH TEMPERATURE MEASUREMENT

BY

ELECTRIC MEANS

BY

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THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Mr. Maurice de Roy Carr

ENTITLED High temperature measurements by electric means

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Electrical Engineer

Ernst Berg
In Charge of Major Work

Ernst Berg
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Ernst Berg

Committee on Final Examination

HIGH TEMPERATURE MEASUREMENT

by

ELECTRIC MEANS.

CONTENTS.

In the thesis of Mr. Karr one or two more slight additions would, I think, increase the clearness. On page 2 a he of course refers to manufacturers in the United States, would it not be well to add this.

On page 3, paragraph marked B, which has no real antecedant.

Very truly yours,

H. H. Stoek

Professor of Mining Engineering.

HIGH TEMPERATURE MEASUREMENT

by

ELECTRIC MEANS.

CONTENTS.

I. INTRODUCTION.

The accurate measurement of high temperatures has come to be a very essential feature of many industrial processes. The pyrometer makes it possible to reproduce with precision any temperature that has been found to yield the best results in operations requiring careful heat treatment. In the making of tinted glass, for example, the proper regulation of the temperature of the furnace is necessary to prevent burning out the color. Instead of depending upon the workman to judge of the condition of the material with his eye, the manufacturer gives instructions to maintain the heat at a certain temperature, knowing then that the output will be of a certain uniform grade. In this manner the variable human element is eliminated and waste prevented. The tempering of tools, the burning of ceramic products, the operation of gas producers, the manufacture of iron and steel and the annealing of castings are a few examples of processes that may be carried on to better advantage with the aid of refined methods of measuring high temperatures. The recording pyrometer is rapidly coming into use as an efficient means of supervising processes requiring heat treatment.

The methods of measuring high temperatures have been greatly improved in the last few years and the making of pyrometers and accessories engages the attention of about a dozen manufacturers. The development of the science of pyrometry has been confined largely to the refinement of a few methods rather than to the evolution of new ones. Leaving out of consideration the expansion thermometer, the ranges of usefulness of present day methods of measuring temperatures may be defined as follows:-

Absolute zero to 1600°C. (3000°F) Electrical Methods
Above 900°C. (1500°F) Radiation and Optical Methods.

While the discussion of the electrical methods constitutes the principal subject matter of this thesis, brief reference is made to a number of the radiation and optical methods, for the reason that electricity is indispensable in their application.

II. GENERAL.

Electricity furnishes two valuable means of measuring high temperatures. One method turns to account the increase in resistance that most substances undergo when heated and the other method depends upon the fact that an electromotive is developed when heat is applied to the junction of two dissimilar metals. Both methods are suitable for use over very wide temperature ranges extending from the region of absolute zero up nearly to the melting point of the substances employed. These methods may be designated the

Resistance Method, or Resistance Pyrometry.
Thermo-Electric Method, or Thermo-Electric Pyrometry.

The resistance method involves the measurement of the change in resistance of a properly protected platinum wire subjected to the temperature to be measured. Platinum is practically the only substance used for this purpose for the reason that its melting point is high and its other properties are satisfactory. Resistance thermometers are suitable for use at all temperatures from - 200°C. to 1200°C. (2200°F). The method is capable of great refinement and furnishes the most exact means of temperature measurement, or control, known today. The bolometer, an instrument involving the resistance principle, is capable of indicating a change in temperature of one ten millionth of a degree C.

The thermo-electric method involves the measurement of the minute electro motive forces developed at the hot junctions of the thermo-electric couples. Platinum and its alloys when properly protected are the most satisfactory metals, every thing considered, for measuring temperatures by this means. Their useful temperature range is 300°C.- 1600° C. Other metals and alloys extend the range down to the region of absolute zero and up to 2100°C. (3800°F).

Both methods outlined require more or less delicate apparatus and careful protection of the element. Hot gases exert marked deteriorating effects upon the metals employed which destroys the value of calibrations and makes measurements subject to large errors.

The radiation pyrometer is a combination of some means for concentrating radiant energy and a delicate resistance thermometer, or a thermo-couple. The optical pyrometers are essentially photometers. The light from the body, or region, the temperature which is to be measured, is compared with that from a standard electric lamp.

III. RESISTANCE PYROMETRY.

1. Theory.

The suitability of a substance for use as the resistance element of a pyrometer depends upon the constancy of the rate of change of its resistance when subjected to repeated heating and cooling and upon the temperature range over which it may be used. Platinum is practically the only material fulfilling all of the requirements. Even platinum fails to meet the needs of the situation, unless it be properly protected. Other metals with high melting points are unsuitable because their resistance is not constant at a given temperature. Instruments made of such materials would not give identical readings twice when subjected to the same temperature, if allowed to cool between observations.

The work of numerous investigators shows that the relation between temperatures measured upon the scale of the platinum thermometer and those measured upon the scale of the gas thermometer may be expressed by the following comparatively simple, empirical formula:-

$$T - t = \delta\,(T/100)^2 - T/100.$$

In this expression, T, is the temperature upon the scale of the gas thermometer, t, the temperature upon the scale of the platinum thermometer and δ, a constant which is different for different samples of platinum, depending upon their purity. Its value is about 1.5 for chemically pure metal.

Since this expression is a parabolic function, readings of the instrument at three known temperatures are sufficient to establish the scale of any given platinum thermometer. The three temperatures recommended for this use are 0°, 100° and 444.6°C., or in other words, the melting and boiling points of water and the boiling point of sulphur. The relation of temperatures upon the platinum scale to the change in resistance of a platinum conductor is shown in the expression given below.

$$t = (R - R_0)/(R_{100} - R_0)\ 100$$

t, is the temperature upon the platinum scale, R_0 the resistance of the wire at 0°C., R_{100} at 100°C and R, at the temperature to be measured. An inspection of this formula shows that temperatures upon the platinum scale are directly proportional to the resistance of the thermometer, the increment in resistance from 0° to 100° C, being taken as 100

degrees. Combining the two expressions given we have,

$$T - (R - R_0)/(R_{100} - R_0)\ 100 = \delta\ (T/100)^2 - T/100$$

The relations indicated above hold only when the platinum is protected from the contaminating effects of hot gases. If not shielded, the element increases in resistance after heating. This increase in resistance is due to chemical changes in the platinum. Fortunately, it is possible to eliminate these effects by enclosing the element in a porcelain, or a platinum tube. Externally glazed porcelain tubes are most commonly used, platinum being too expensive.

The range of the platinum thermometer extends from the region of - 200°C (- 330°F.) up to 1200°C. (2200°F.) At about 1200°C., platinum begins to volatilize and readings taken above this temperature are untrustworthy. Between the limits mentioned, the resistance method affords the most precise means known for measuring, or controlling temperatures. The precision attainable is dependent largely upon the precision with which the resistance measurements can be made.

2. Apparatus.

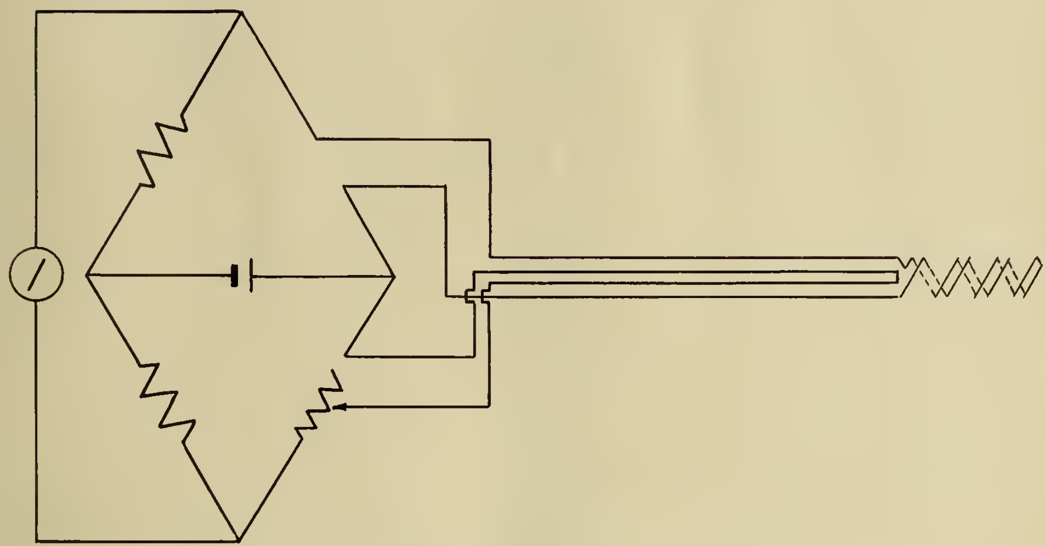
The resistance method of measuring temperatures is easily applied in a laboratory. Its application involves simply the measurement of the change in resistance of a properly protected platinum wire, the constant of which can easily be determined.

For industrial applications, suitable portable instruments and rugged platinum thermometers are necessary. At least two companies, The Cambridge Scientific Co., of Cambridge, England, represented in this country by the Taylor Instrument Companies, Rochester, N. Y. and the Leeds and Northrup Co. of Philadelphia, have placed resistance pyrometers upon the market.

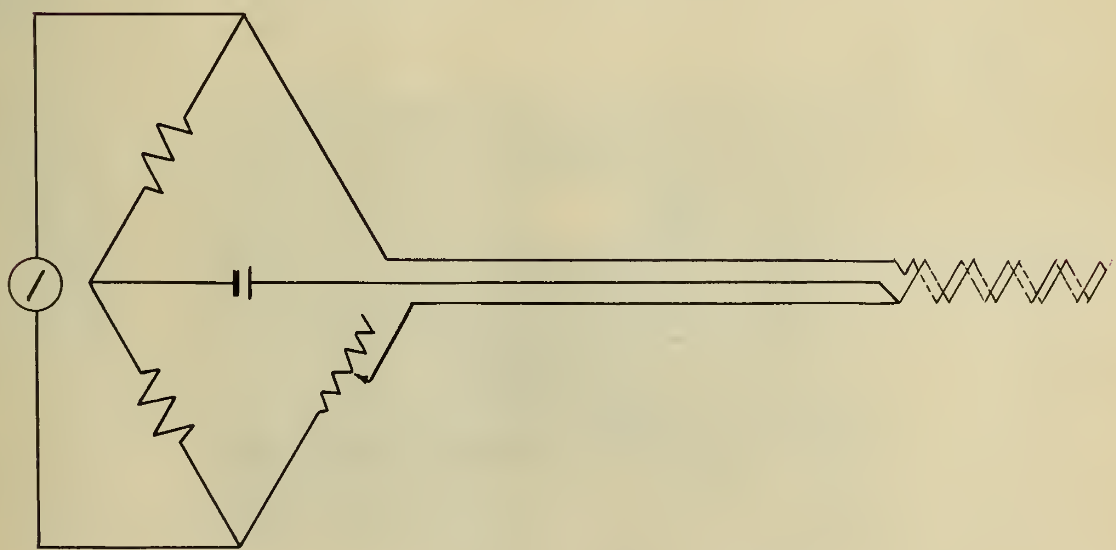
The Cambridge company was the first concern to manufacture satisfactory apparatus of this kind for commercial uses. Both companies make platinum thermometers and indicating and recording instruments for use with the same. Substantially the same principles are applied by each maker. (See drawing of theoretical circuits.)

The resistance thermometer of the Cambridge Company consists of a coil of fine platinum wire wound upon a mica frame and enclosed in a porcelain tube. (See cut). The terminals of the coil are connected with suitable leads to

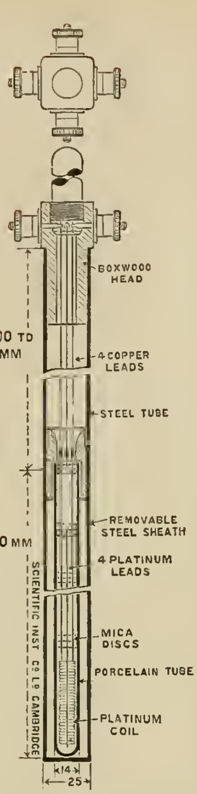
CIRCUITS OF RESISTANCE PYROMETERS



FOUR LEAD TYPE



THREE LEAD TYPE



Cambridge Scientific Co's. Resistance Thermometer.

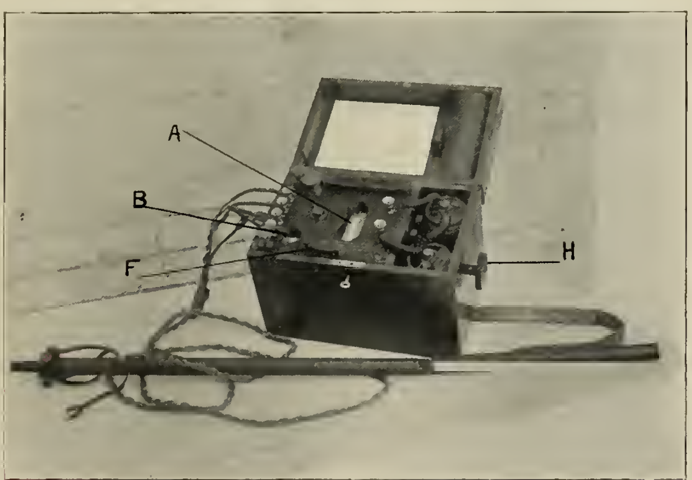
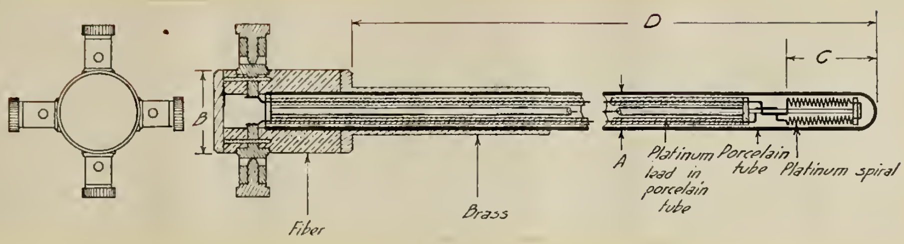
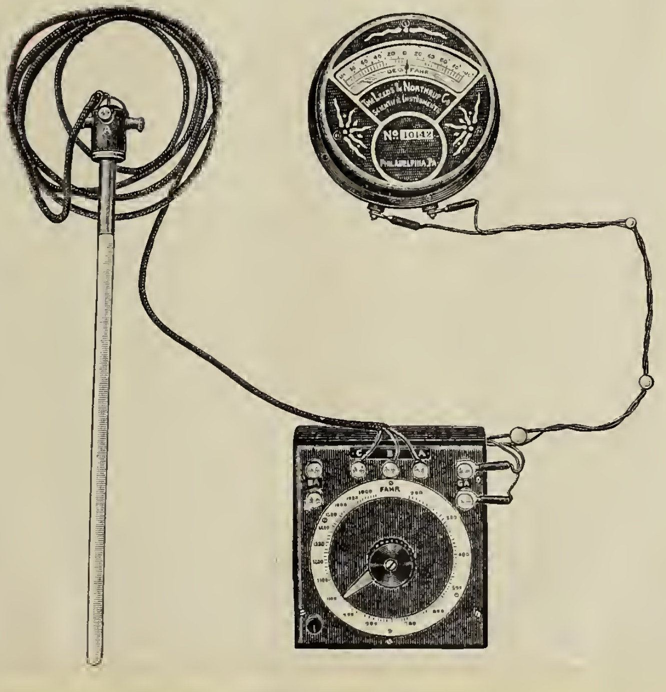


FIG. B.—CALLENDAR AND GRIFFITHS' PATENT RESISTANCE THERMOMETER CONNECTED TO A "WHIPPLE" PATENT TEMPERATURE INDICATOR; SUITABLE FOR MEASURING THE TEMPERATURE OF BOILER FLUES, ETC.

Whipple Indicator.



Leeds and Northrup, 4 Lead Thermometer



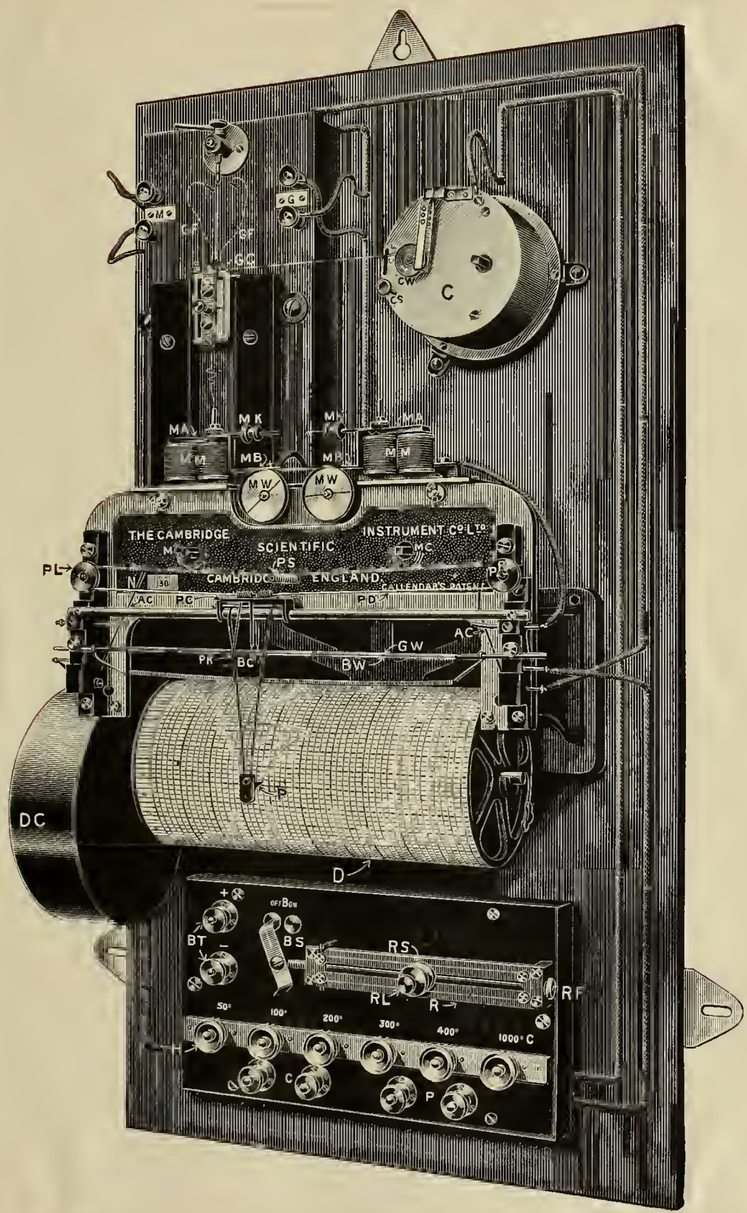
Leeds and Northrup Indicator.

binding posts upon the handle of the instrument. It will be observed that there are four posts. Two of these are the terminals of leads which serve to compensate for temperature changes. These compensation leads are similar in all respects to the leads coming from the coil. They are connected together at a point so that the resistance of the loop they form in the tube is equal to that of the leads of the coil. The purpose of this compensation loop is seen by an inspection of the drawing. Its use eliminates the necessity for corrections for changes in the resistance of the leads connecting the thermometer with the instrument. The connection leads consist of four parallel, identical conductors provided with suitable armor for mechanical protection.

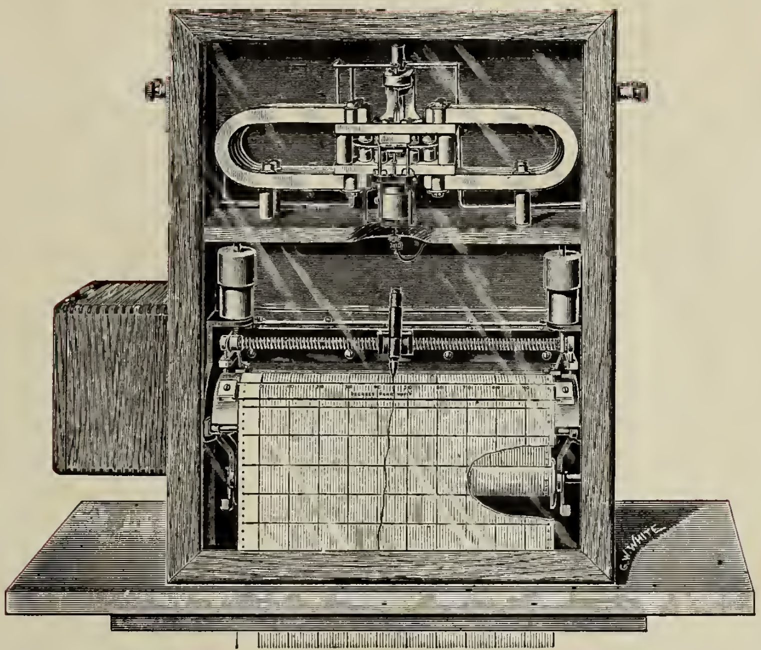
The Leeds and Northrup resistance thermometer resembles the Cambridge Company's instrument in principle of operation and in general appearance. It, however, requires but three leads, except in the case of thermometers for the highest temperatures, in which the practice of the English concern is followed. The coil in these thermometers is made of platinum wire heavy enough to render the use of a mica support unnecessary. Both companies supply metal sheaths for protection of thermometers from mechanical injury. For the highest temperatures, these sheaths must be dispensed with and reliance placed upon the naked, porcelain tube.

The instruments used in connection with platinum thermometers are modified forms of the Wheatstone bridge. The Cambridge Company's instrument is known as the Whipple indicator. It consists of a wooden box about one foot on a side and weighing nearly 20 pounds. (See cut). Electrically, it is a Wheatstone bridge with a very long slide wire wound upon a revoluble drum turned by the disk, H. The scale beside the wire travels with it and is laid off in degrees. To make a reading it is necessary to press the key, F, and turn the drum until the galvanometer, B, shows no deflection. The temperature is then read off the scale which shows at the window, A.

A Leeds and Northrup indicating instrument is shown in the accompanying illustration. It is also made in a number of other forms, all of which employ the bridge principle, however, The type of instrument shown is admirably adapted for use in temperature control, the workman being able to tell by a glance whether his temperature is too high, or too low. The apparatus shown in the lower part of the picture may be located in the superintendents' office, or any other place out of the workman's reach. The company also makes a portable balance indicator of about the size and weight of an ordinary voltmeter.



Callendar Recorder.



Leeds & Northrup Temperature Recorder without Bulb.

The stationary form of instrument used in connection with the Cambridge Company's resistance thermometers is known as the Callendar recorder. (See cut). It is a complicated mechanism consisting of a Wheatstone bridge in which the movable contact is shifted along the slide wire by clockwork that is controlled by the galvanometer. The contact carries the pen which makes a record upon a wide strip of paper moved by a clock. The leads from the thermometer are connected in opposing arms of the bridge so that any change in the resistance of the thermometer coil destroys the balance. This causes a deflection of the galvanometer which starts a clock that drags the contact point and pen in the proper direction to restore the balance. The device is a very ingenious piece of mechanism and upon the whole, reliable in operation. It is adapted for recording any physical phenomenon that is manifest by a change in resistance. Thus it may be used as a recording voltmeter, a recording ammeter, or a recording wattmeter, provided the proper accessories are employed.

The recorder manufactured by the Leeds and Northrup Co., shown in the cut, operates upon substantially the same principle as the Callendar recorder.

IV. THERMO-ELECTRIC PYROMETRY.

1. Theory.

Thermo-electric pyrometry is made possible by the fact that the thermo-electromotive produced at the junction of two dissimilar metals is proportional to the temperature of the junction. Strictly speaking, the electromotive force is the algebraic sum of the e. m. fs. of all of the junctions in the circuit. In practice, except for precise measurements the temperatures of the colder junctions may be disregarded, provided they are low in comparison with the temperature to be measured and are constant. Such a combination of metals is known as a thermo-electric couple, or more simply, a couple. Not all metals, however, are suitable for use in couples. Some are unfit because of their low fusing points, others because of their small thermo-electric power and others because of the production of parasitic electromotive forces. Platinum and its alloys of iridium and rhodium, silver, copper and a few alloys of base metals are practically the only substances used for ordinary thermo-electric couples. Couples are sometimes made of iridium and an alloy of iridium and ruthenium. Temperatures as high as 2100°C. (3800°F.) can be measured with couples of this kind, but they are not suitable for use outside of a laboratory.

Of all of the metals mentioned, platinum and an alloy consisting of 90 percent platinum and 10 percent rhodium are the most satisfactory for temperatures up to 1600°C. (2900°F.) This combination is known as the LeChatelier couple. Its useful range does not extend much below 300°C. (600°F.)

Platinum and its alloys require careful handling and protection to secure the best results. Protection of the heated portion from the contaminating effects of hot gases, particularly in a reducing atmosphere, is as essential a feature of thermo-electric pyrometry as it is of resistance pyrometry. All of the volatile metals, such as silver, copper, zinc and antimony attack platinum readily producing changes that alter the constants of couples. Silicon in a reducing atmosphere is also detrimental to thermo-couples. The only way to avoid the injurious effects, is to insert the couple in a porcelain, or platinum tube.

The relation between the electromotive force of the platinum-rhodium couple and temperature is expressed by the following equation:-

$$e = m\,(T^{n} - t)$$

e is the electromotive force, m is a constant, T is the temperature of the hot junction and t, the temperature of the cold junctions. If the cold junctions are at 0°C., the expression reduces to,

$$e = m\,T^{n}$$

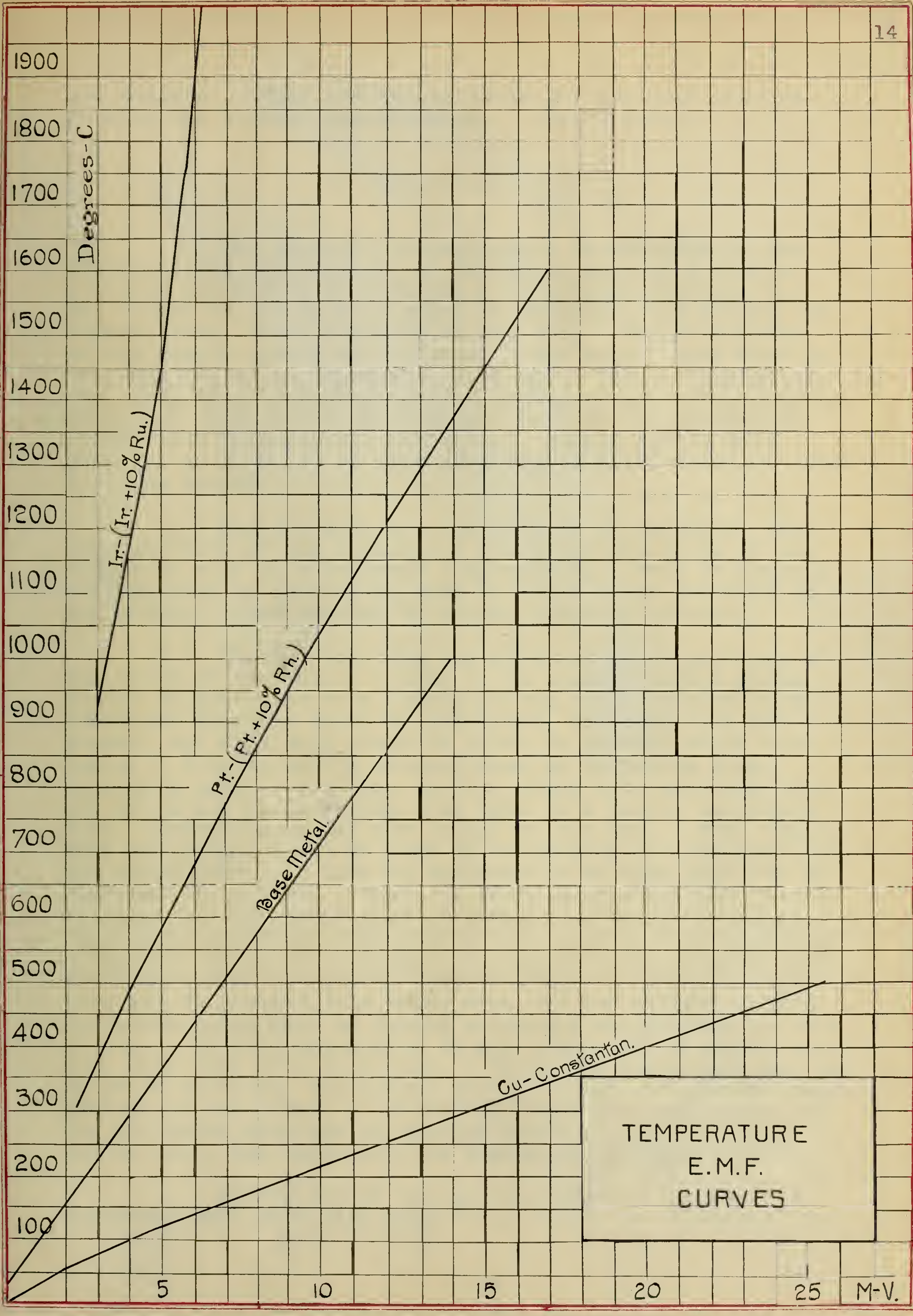
which, upon taking logarithms, becomes

$$\log e = n \log T + \log m$$

This is a straight line, necessitating the determination of the e.m.f. of the couple at but two points to standardize it. This formula is accurate to within 2°C. and is suitable for all but the most precise measurements.

Couples of copper and an alloy known as constantan, iron and constantan, gold and platinum are suitable for the range from the region of absolute zero to 600 degrees C. (1100°F.) (See Curves).

Couples made of such base metals as iron, nickel and chromium and their alloys are now used extensively as substitutes for platinum and its alloys for temperatures up to 1200 degrees C., or higher. In general they yield higher electromotive forces and their e.m.f. temperature relations are more nearly linear. They are open to the objection that they must be renewed frequently, but upon the other hand they



TEMPERATURE
E.M.F.
CURVES

are cheaper. They are not suitable for the most precise work at the highest temperatures. (See Curves).

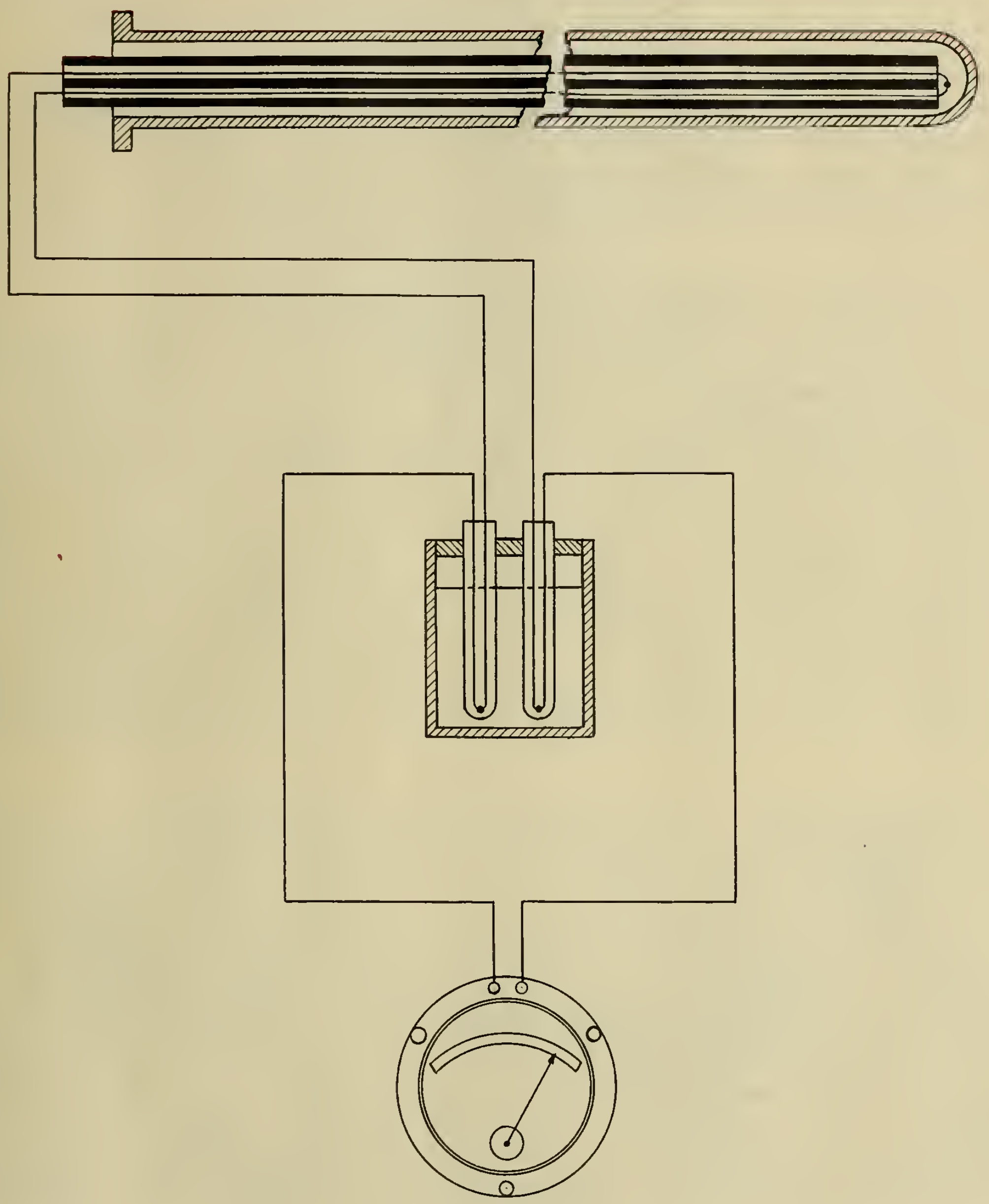
2. Apparatus.

The standard thermo-couple recommended by the Physikalische Reichanstalt of Berlin is made of a wire of platinum and a wire of platinum + 10 percent rhodium, 0.6 mm. (About No. 23 B. & S. gage) in diameter, 1.5 meters (59 inches) long, fused together at one end. The resistance of the couple should be 1.6 ohms. The metals used must be pure and the alloy uniform throughout. The uniformity of the alloy is as important as the purity of its constituents. Points of variation along the wire will act as junctions giving rise to parasitic currents. Such a couple will generate an E. M. F. of approximately 17 milli-volts at 1600° C. (See Curve).

For the most precise work it is essential that the junctions of the instrument leads and the wires of the couple be kept at a constant temperature. This is usually accomplished by insulating them in glass tubes immersed in ice water. (See drawing of thermo-electric circuit).

The hot junction and at least those portions of the wires of the couple likely to be exposed to hot gases should be protected from contamination. It is also very essential that the wires be insulated, not only from the ground, but from each other in order to prevent short circuits. This is easily accomplished by threading them through a small porcelain, or fire clay, tube provided with two holes and by enclosing this tube in a larger porcelain tube, externally glazed and closed at one end. Some times, when the couple is to be used at relatively low temperatures, the outer porcelain tube is enclosed in an iron pipe for mechanical protection. Tubes of fused quarts are now coming into use for the protection of couples. They are not so fragile as porcelain tubes and may be used at very high temperatures. They also possess the valuable property of withstanding sudden changes in temperature. It is said that they may be plunged into water when red hot without injury. Porcelain tubes must be heated gradually and allowed to cool slowly. If this precaution is not taken, it is almost certain that they will be broken. While the inner tube may be in short sections, the sheath must be intact to prevent gases getting to the wires. Fire clay tubes are some times used for the outer envelope in special cases., Platinum tubes can be used, but their cost is almost prohibitive.

Nearly all of the manufacturers of pyrometric apparatus make what they call "fire rods", or "elements" for



THERMO-ELECTRIC CIRCUIT

insertion into the region where the temperature is to be measured. These are generally arranged with a handle and sometimes a guard to shield the hand is provided. They correspond to the thermometers used in resistance pyrometry. The thermo-couples contained in them may be either platinum-rhodium, or base metal elements, depending upon the temperatures to be measured. Flexible leads extend from the rod to the instrument.

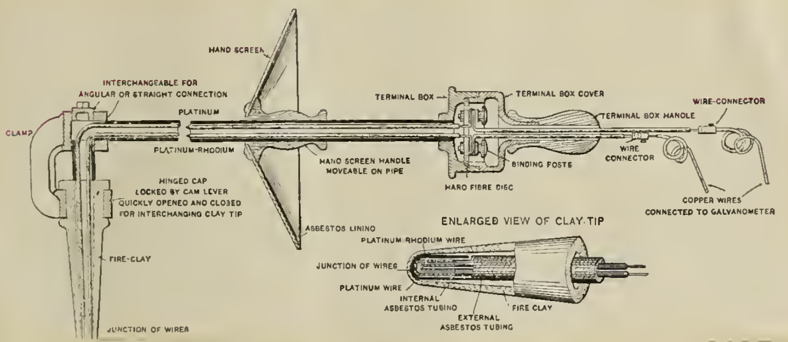
The electromotive forces generated by thermo-couples are measured by potentiometer, or galvanometric methods. The former is well adapted for strictly laboratory purposes, but is not suitable for use in installations requiring an instrument that can be moved readily. The method is used only for the most precise work.

The galvanometric method involves the use of some form of D'Arsonval milli-voltmeter of which there are many upon the market at the present time. The principal consideration involved in the choice of such an instrument, aside from mechanical features, is that its resistance should be high in comparison with that of the couple and the remainder of the circuit. This precaution is necessary in order to render negligible the effects of changes in the resistance of the external circuit. In general, a resistance of 400 to 500 ohms is sufficient. Many instruments for this purpose are calibrated to read temperatures directly when used in connection with a given couple. Some instruments are also calibrated to read millivolts and may be used in connection with any couple if its temperature e.m.f. curve is at hand.

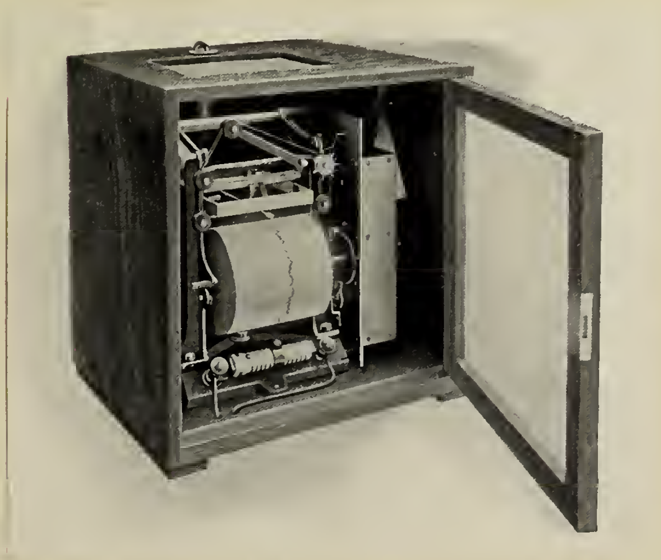
Pivot instruments suitable for use with the noble metal couples are now manufactured. Base metal couples, which yield higher electromotive forces than platinum couples, give excellent results with pivot instruments. Most of the higher grade galvanometers for thermo-electric work are of the suspension type, however. They consequently require careful handling and leveling to avoid introducing errors. The current produced in a thermo-couple circuit is exceedingly small. In the case of the standard LeChatelier couple used in connection with a circuit of 500 ohms total resistance, it is only .000034 ampere. Compared with .01 ampere required to produce full scale deflection upon an ordinary voltmeter, for example, it is easily seen that there is not very much power available for overcoming friction.

Several recording milli-voltmeters for use in connection with thermo-couples are now made. In most cases, these instruments are indicating milli-voltmeters with a pen attached to the needle which swings over a strip of paper moved by clockwork. The principal consideration involved in the design of such an instrument is the elimination of the

A Base Metal Couple Pyrometer.



A "Fire Rod".



A Thermo-Electric Recorder.

friction between the pen and the paper, This is often accomplished by allowing the pen to swing free normally and providing clock controlled mechanism for lifting the paper against the pen, or for pushing the latter down at regular intervals. The record thus consists of a series of dots. Sometimes instead of attaching the pen to needle, the latter is pushed down against an inked thread which makes a dot on the record tape. At least two manufacturers, use a circular record chart, the recording part of the instrument being very much like that of the well known recording gages and electrical instruments made by the Bristol Company. Provision is made for intermittent contact of the pen with the paper.

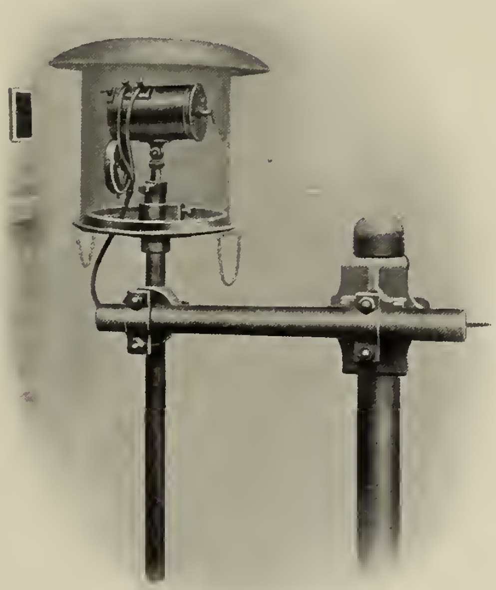
V. OPTICAL AND RADIATION PYROMETERS.

Optical pyrometers may be defined as convenient aids for measuring temperatures with the eye. Optical and radiation methods are based upon the fact that the energy radiated by a hot body is proportional to its absolute temperature. The optical instruments usually depend upon the photometric principle which may be somewhat crudely stated to be the comparison of a light of known temperature with the light emitted by the body whose temperature we would measure. Electricity is employed inthese instruments principally as a convenient means of lighting this standard lamp. Two optical pyrometers are so constructed that the heated filament of a lamp is viewed in the same field as the hot body. When the radiation from the body and from the filament are of equal intensity, the filament becomes invisible. The most important factor in the accuracy of this instrument is the constancy of the standard lamp.

The radiation pyrometer utilizes the total radiation incident upon it from the hot body. It consists of a convex lens, or a concave mirror, with a delicate thermocouple, or resistance thermometer, at the focus. When a thermo-couple is used, it is connected to a milli-voltmeter which is so calibrated that it indicates the temperature of the hot body. By use of specially sensitive couples it is possible to measure temperatures as low as 600°C (1100°F.) The instrument is assembled in a tube open at the end turned toward the source of heat.

Optical and radiation pyrometers are used in much the same manner as a telescope- that is they are sighted upon the object, the temperature of which is to be measured. In this manner of use lie their advantages and their disadvantages. They are obviously not subject to the deteriorating effects of heat and there is theoretically no upper limit to the temperature range over which they may be used. Their disadvantages are that they are not suitable

Radiation Pyrometry



FERY RADIATION PYROMETER, IN WEATHER-HOOD SIGHTED INTO FIRECLAY TUBE.
About 1-10 full size.

for measuring temperatures of small spaces and provision must be made to sight them upon the region, the temperature of which is to be measured. They are however, the only means available for the measurement of temperatures above the range of the strictly electric pyrometers.

The optical pyrometers cannot be employed, except for temperatures high enough to cause luminosity. The radiation types may be used for lower temperatures since they depend upon total radiation. The optical instruments are not easily made self registering, but recording radiation pyrometers are manufactured by at least two companies. The Cambridge Scientific Company, makes a thread recorder and the Brown Instrument Co. of Philadelphia, employs the same instrument that it uses in connection with its thermo-electric pyrometers.

VI. INDUSTRIAL APPLICATIONS.

1.- Resistance Method.

Resistance pyrometry is well adapted for use in many different kinds of industrial processes. The lists of purchasers of resistance pyrometers given in the catalogs of the two principal makers include chemical works, gas plants, glass works, breweries, steel works, annealing, hardening and smelting furnaces and many others. The method is of course limited in its application to those processes involving temperatures of 1200°C., or lower. Both indicating and recording instruments are employed. The former are of most value as a guide for the workman in the performance of his duties. The latter enable the superintendent to know the temperature conditions that existed at any time and furnish an impartial, unbiased cheek upon the workman. Both kinds of instruments are often used in conjunction. It is quite common practice to employ switch boards to which a number of thermometers may be connected for use with a common instrument.

Resistance pyrometers are used a great deal for measuring moderate and low temperatures. For instance they are often used to indicate such temperatures as that of air soils and water, of grain in elevators and cars, of cold storage rooms and of food in the process of manufacture.

2. Thermo-Electric Method.

The thermo-electric method is suitable for use in practically any process that the resistance method may be used, and in addition to those involving temperatures as high as 1600°C. Thermo-couples are used extensively in the burning of clay products, to some extent in foundry work, steel making, experimental work, glass making, tempering and annealing, galvanizing and many other processes involving high temperatures. The number of users is constantly increasing as the value of accurate control of temperature conditions becomes better understood. The users of thermo-electric pyrometers out number those employing the resistance type.

It is becoming common practice when a number of couples are used in a plant, in different ovens for example, to install a switchboard and a common instrument which may be connected to any couple attached to the board. Recording instruments which may be under lock and key are often employed as a means of supervision. The installation of permenent wiring in a substantial, workmanlike manner is coming to be recognized as a profitable investment from an engineering and economic standpoint. Some of the manufacturers of pyrometers prefer to install their own apparatus and one concern at least, insists upon so doing. A new field of engineering is slowly being evolved. In twenty-five years the pyrometer will be considered as essential a part of a plant as the furnace.

3. Optical and Radiation Method.

The optical and radiation pyrometers are especially adapted for use in connection with furnaces involving temperatures too high for the electric pyrometers, or conditions under which the latter can not be installed. Their intelligent use under varying conditions calls for greater technical knowledge than either of the other methods. On the other hand, they are not subject to the deteriorating effects of heat and if used continually for the same purpose are probably to be preferred to the electrical instruments. Their inherent accuracy is greater at the higher temperatures owing to the fact that radiant energy increases as the fourth power of the absolute temperature of its source.

VII. CALIBRATION OF PYROMETERS.

Owing to the deteriorating effects of heat, it is essential that pyrometers be calibrated at intervals. This is true, particularly if the metal of the element has been subjected to hot gases. Base metal couples should be checked frequently to detect changes in constants. Platinum resistance thermometers made by either of the two companies mentioned can be depended upon for considerable periods of time, unless subjected to abuse. They should be checked occasionally, however for changes in constants, especially if used for precise work.

Electric pyrometers are calibrated by subjecting them to known temperatures. This may be done in either of two ways. One method is to use a number of fixed temperatures, such as the melting, or freezing points, of certain substances. The other method is to compare readings of the pyrometer with those of a standard instrument subjected to the same conditions.

The first method is the more exact of the two and is used for precise work. The freezing points of certain metals have been determined many times with great exactness in terms of the scale of the gas thermometer, the standard with which all pyrometers are ultimately compared. The freezing points of tin, cadmium, lead, zinc, antimony, silver, copper, gold, and platinum may be used. In the metals mentioned, the freezing point is marked by a period of stationary temperature of several minutes duration in some cases. This affords ample time for a number of readings. Readings taken with several metals afford sufficient data for a calibration. The number of points required depends upon the formula used. In the case of a resistance thermometer, three points are necessary, if the Callendar formula is used. Two points a considerable distance apart, as for example, the zinc and copper freezing points are sufficient to establish the scale of the Pt- (Pt + Rh) couple, if the formula given above is used.

Freezing point determinations should be made with pure materials. It is not necessary to use chemically pure metals in all cases however, except for the most refined work. Commercially pure copper gives results within a degree of those given by chemically pure metal. Pig and pipe lead have freezing points 1-1/2° to 2°C. below that of pure lead. Commercial tin has about the same freezing point as the pure metal. Antimony upon the contrary is a metal that must be pure to give correct results. Antimony also exhibits the phenomenon known as, "under cooling". That is, the temperature goes down for a time and then suddenly rises 30°C, or

more, at the moment of freezing, after which it again decreases.

The electric resistance furnace is usually employed in the freezing point method, the metal charge being placed in a graphite crucible. The electric furnace is admirably adapted for calibration purposes because it is easily controlled and because there are no contaminating gases present.

It is necessary to prevent oxidation of the charge in some cases by covering the surface of the molten metal with powdered graphite. Copper so protected gives a freezing point of 1083°C. If exposed to the air, the freezing point is 1065°C. a very constant temperature, however.

In the second method mentioned, the pyrometer to be calibrated is inserted in a furnace beside a standard pyrometer and the readings of the two instruments compared. The horizontal type of furnace is usually employed. This method is the one used by the Bureau of Standards, except for the most refined work.

The method is one that can be used to advantage by industrial concerns. It of course necessitates keeping a standard fire element that should be used for no other purpose. Such a thermometer, or couple, may well be a certified instrument, the fees of the Bureau of Standards being moderate in comparison with the cost of pyrometric apparatus. Ten dollars and transportation charges will meet the expense of any ordinary calibration of an electric pyrometer.

In works using many thermo-couples under trying conditions, it may result in considerable saving to employ cheap base metal couples and to check them at frequent intervals against a standard platinum couple. The base metal couples give higher electromotive forces and can be used with more rugged instruments than platinum couples. They also can be made heavy so as to resist mechanical injury and do not require such elaborate protection from the effects of hot gases as do platinum couples. Of course, plants whose processes involve temperatures greater than base metal couples are capable of withstanding must necessarily employ platinum couples exclusively.

Resistance furnaces for calibrating purposes may be purchased from a number of concerns. A furnace suitable for many purposes and giving good results up to temperatures as high as 1000°F. can be constructed at a slight cost from materials easily picked up in almost any shop. It is somewhat short lived, but this objection is offset by the low cost of replacing it. The writer has constructed a number

of such furnaces. The materials required are a clay, or porcelain, battery jar, several yards of iron wire of about No. 20 gage, some mineral wool, asbestos, or magnesia pipe covering, and a few fire bricks. One layer of wire is wound around the jar beginning about one half inch from the bottom and ending about the same distance from the top. A space equal to several times the diameter of the wire is left between each convolution. The jar is then placed in a receptacle made of brick laid in fire clay, or inside a drain tile, and packed with mineral wool. A section of magnesia pipe covering may be used instead of the mineral wool. Packing is placed around the closed end of the jar and a removable plug of non-inflammable material is inserted in the open end. Pyrometers are introduced through holes in this plug. The ends of the wire are left long enough to bring out for connection to the circuit. A theatre dinner in series with the winding furnishes an admirable means of regulating the current flow. A water rheostat may be used if desired.

The writer is at present constructing a resistance furnace of slightly modified design. A porcelain tube 3 inches in diameter and 7-1/2 inches long is wound with Nichrome ribbon .007 inch thick and 1/8 inch wide. About 1/8 inch space is left between each convolution. The insulation is to be at least 3 inches of mineral wool packed around the tube in a drain tile mounted in a horizontal position upon suitable iron legs. The ends of the porcelain tube are closed, except for a hole 3/4 inch in diameter for the insertion of pyrometers. While this furnace has not been tested, it is almost a duplicate of one that has given satisfactory service for tempering tools. It is expected that a temperature of 1200°F., or higher, can be attained.

The accurate calibration of electric pyrometers is absolutely essential. The effect of heat is deteriorate any known material suitable for pyrometric use. Since there is no means by which these destructive effects can be eliminated, the only recourse is to subject the instrument in question to test as often as experience shows to be necessary to maintain the standard of accuracy required. Platinum couples can be restored in most cases by glowing them at yellow heat for several hours in an electric circuit. In case this does not restore the material to its original condition, it still has a market value for other uses. Base metal couples, being cheap, can be thrown away if contaminated.

The testing of radiation pyrometers involves the application of principles of optical methods lying out side the field of electrical measurements.

VI. COMPARISON OF METHODS.

No one method of pyrometry is suitable for use in every situation. The proper method cannot be chosen without careful consideration of all of the conditions under which the apparatus is to be used. The questions of temperature range, precision of measurement desired, protection required for the elements, intelligence necessary for operation, necessity for records, ease of installation, first cost and cost of up keep must be considered in the choice of a pyrometer for a given plant. These are discussed briefly in the following paragraphs which are later summarized in tabular form.

1.- Temperature Range.

The temperature range of the resistance method is limited to 1200°C. (2200°F.) if platinum is employed. The range of the thermo-electric pyrometer is greater, but couples of different materials must be used in different parts of the range. Copper-constantan, iron-constantan and platinum- gold couples are available for use from the lowest temperatures to the lower limit of the Pt - Rh, or Pt - Ir, couple and the Ir - Ru couple from the upper limits of the latter to the highest temperatures that can be measured by the thermo-couple pyrometer. As pointed out previously, the last named couple is not a commercial instrument. The range of the radiation pyrometer is from 600°C. (1100°F.) up. Theoretically, it has no upper limit.

2.- Precision of Measurement.

The precision of measurement is greatest when the resistance method is employed. In many industries the precision of the laboratory is not required. The precision with which a workman is likely to make a given measurement is not the same as the precision of which the instrument is capable. The workman is prone to judge the accuracy of his measurement by the length of the portion of the scale covered, rather than by the temperature to which the space corresponds. For this reason instruments with long scales are especially recommended. In this respect the resistance type of instrument, such as the Whipple indicator with its long temperature scale, meets the above requirement admirably.

3.- Protection of Element.

The resistance method is at a distinct disadvantage considered from the standpoint of protection required for the element. The radiation pyrometer having no part subjected to high temperatures requires no protection from heat. Platinum couples need the same protection as the resistance thermometer, but are more easily re-calibrated if contaminated. The base metal couples may be used without protection.

4.- Operation.

The operation of the Whipple indicator requires some manipulation upon the part of the observer before a reading can be taken. It is not possible for him to know, except by going to the indicator whether the temperature is varying and then he can not determine the amount, except by balancing the bridge. If the temperature is fluctuating very much it is impossible to measure it with any degree of certainty. With the Leeds and Northrup instrument shown, it is possible to detect variations after balancing the bridge and the amount and direction of the change is also apparent. In other respects the operation of the apparatus made by the two companies is about the same.

The thermo-electric pyrometers give visual indications of their readings and require no preliminary operations when a reading is to be taken. The method of using a radiation pyrometer depends upon the installation, but the actual readings are made as in the thermo-electric pyrometer.

5.- Recording Instruments.

The three methods are about upon a par in the matter of recording temperatures. The thermo-electric recorders are simpler, but probably no more reliable.

6.- Permanent Installations.

The principal consideration in the matter of installation is the wiring, which should be well done in either case. The resistance pyrometers require three to four leads, but their resistance is immaterial provided it is the same for each conductor. Thermo-electric installations require only two leads for each couple, or in some cases one lead and

a common return, but these must be of low resistance which in no case should be more than one to two ohms. Radiation pyrometers use the same kind of wiring as thermo-couples.

7.- Cost of Apparatus.

The cost of apparatus ranges from $50.00, or less, to as high as $450 according to quotations and catalogs. Some base metal couples and suitable indicating instruments can be purchased for the lower figure. The larger figure is for a recording, radiation pyrometer. A certified Pt - Rh couple from Heraeus with a Siemens and Halske galvanometer and protecting tubes can be purchased for about $150.00. A five foot Pt - Rh couple costs about $60.00. Shorter lengths cost proportionately less. Base metal couples cost $5.00 to $10.00 if purchased of makers. Some kinds can be made for a few cents. Pivot galvanometers, or milli-voltmeters, suitable for use with base metal couples can be purchased for less than $50.00. A good imported suspension type of galvanometer can be gotten for $75.00 (Siemens and Halske). Porcelain and quartz protecting tubes cost from $3.00 to $15.00.

The Whipple indicator costs in the neighborhood of $200.00 with a thermometer. A Leeds and Northrup indicator and thermometer can be bought for about $150.00.

Radiation pyrometers cost from $150.00 to $300, depending upon the make— the latter price being for an imported instrument.

8.- Cost of Up Keep.

This is a variable quantity for either of the strictly electrical methods. Leaving wiring out of consideration, the radiation instruments should cost almost nothing for up keep. The cost in the case of the resistance and thermo-electric methods depends entirely upon use. Platinum thermo-couples can be restored by glowing and can be recalibrated. If past restoration the metal can be salvaged. Base metal couples are easily calibrated and if necessary cheaply replaced. If the use of resistance pyrometers is severe, new thermometers may be necessary, making up keep charges high.

9.- Tabular Comparison of Methods.

Feature Compared	Methods		
	Resistance	Thermo-electric	Radiation
Temp. Range	Absolute zero to 1200°C.	Absolute zero to 2100°C.	From 600°C. up.
Precision of Measurement	Within 1°C.-0° to 500°C. 3°C. 500° to 1000°C. with Whipple Indicator.	Depends upon instrument, couple and leads. Under best conditions 2° at 1000°C. using galvanometer.	10° at 1000°C. Less at lower temperatures for Féry.
Protection of Element	Must be enclosed in porcelain tube to protect from contamination by hot gases.	Platinum couples must be enclosed in porcelain. Base metal couples may be exposed.	No part subjected to high temperatures.
Operation	Bridge must be balanced before reading can be made.	Readings made by inspection of an instrument.	Same as thermo-electric pyrometer.
Recorders	Complicated, but on whole satisfactory.	Simple and satisfactory in best types.	Same as thermo-electric recorders.
Permanent Installation	Leads of 3 or 4 conductors required. Resistance immaterial. Can be used with a switchboard. Thermometers any distance from instrument.	Only 2 wires required, but resistance must be low. Can be used with a switchboard. Elements may be considerable distance from instrument.	Must be located where it can be sighted on hot body. Instrument may be at distance. 2 heavy leads required.

Cost of Apparatus	Indicating instrument and thermometer $150 to $250 Recorder, $200. to $400.	Platinum couple and galvanometer $100 and up. Base metal couples and instrument $50 and up. Recorders $125 and up.	Indicating instrument $150 to $300. Recording instrument $250 to $450.
Cost of Up Keep	Depends upon use. Great if thermometers must be replaced. Calibration more expensive than for couples.	Couples of Pt can be salvaged. Base metal couples cheap enough to throw away. Calibration fairly easy.	Practically nothing.

IX. CONCLUSION.

The art of measuring high temperatures has been developed greatly in the last few years and much excellent pyrometric apparatus is now upon the market. The greatest development has been along a few lines, although probably every physical, or chemical change, caused by heat has been investigated at some time with a view to using it as a means of measuring temperature. However great the development, it cannot be said that we are yet able to gage high temperatures repeatedly with the precision that we can measure weight, or electrical quantities, repeatedly. Single measurements can be made it is true, but not repeatedly with such precision, owing to the fact that the effect of heat is to change the physical and chemical properties of the pyrometric material. Optical and radiation instruments are not open to this objection, but have other inherent limitations. Optical methods depend to some extent upon the eye and the radiation methods are limited in their application. Unless some new substance or principle is discovered, future improvements will be along the line of refinements in present day methods. Since the limitations of pyrometry as practiced to-day are inherent, the education of the users to recognize them and to govern themselves accordingly is necessary if the arts are to be improved by their employment.

X. BIBLIOGRAPHY.

The following list of references is by no means complete, nor is it intended to be. It, however, includes a sufficient number of works to give an engineer all of the information needed upon the subject of electrical pyrometry, unless he intends to specialize. The works mentioned are easily obtained. The catalogs sent out by the companies whose names are given in the accompanying list, contain a great deal of valuable information about apparatus and many hints concerning the use of pyrometers.

1. High Temperature Measurements.
By Chatelier and Boudouard. Translated by Burgess. This work is the most comprehensive treatise published on the subject of high temperature measurements. It contains an excellent bibliography. Published by Wiley and Sons. Price $3.00.

2. Methods of Pyrometry.
By C. W. Waidner. Reprint from the Proceedings of the Engineers' Society of Western Pennsylvania. A valuable paper by a reliable authority upon the subject. It covers practically the entire field in a brief, comprehensive manner. The pamphlet may be had by applying to the Secretary of the society, Pittsburgh.

3. Optical Pyrometry.
By C. W. Waidner and C. K. Burgess. Reprint from Bulletin No. 2 U. S. Bureau of Standards, Washington, D. C. An authoritative discussion of the theory and apparatus of optical pyrometry. Some attention is devoted to radiation pyrometers.

4. Platinum Resistance Thermometry at High Temperatures.
By C. W. Waidner and G. K. Burgess. Published in Bulletin No. 2. Vol. 6 of the U. S. Bureau of Standards. A very comprehensive treatise upon the subject. It contains much information regarding the calibration of instruments by the melting point method.

5. Pyrometer Testing and Heat Measurements.
Circular No. 7. issued by the U. S. Bureau of Standards, Washington, D. C. This publication contains a great deal of valuable information regarding pyrometers and their calibration. It is sent free of charge upon application.

6. University of Illinois.
Bulletin No. 36, Eng. Exp. Station. By Clement and Egy.- Appendix contains definite information regarding the calibration of couples by the melting point method.

XI. MANUFACTURERS OF PYROMETRIC APPARATUS.

The manufacturers given are the concerns whose advertisements are seen most frequently in the technical journals of the day. The writer has used apparatus made by at least half of the firms listed. Some of the concerns, however, are known to the author only through their literature, or by their reputation in other lines.

1. Bristol Company, Waterbury, Conn.
   This company, which also manufactures the well known line of Bristol recording gages and electrical instruments, makes the pyrometric apparatus formerly put out under the name of Wm. H. Bristol, New York. The company makes thermo-electric apparatus including thermo-couples, indicating and recording instruments. The indicating instrument is gotten up in the form of the ordinary voltmeter. The recording instrument is designed for a circular record chart.

2. The Brown Instrument Company, Philadelphia, Pa.
   Makers of base metal and platinum-rhodium couples, indicating and recording instruments. The indicating instruments are made in round and edgewise wall types and in portable form. The recording instrument is of the type employing a circular record sheet. The company also makes a radiation pyrometer.

3. Cambridge Scientific Company, Cambridge, England.
   Represented in this country by the Taylor Instrument Companies, Rochester, N. Y. This company manufacturers platinum, resistance pyrometers, the Whipple Indicator, and the Callendar Recorder. The company also manufactures platinum-rhodium thermo-couples, indicating and recording instruments for use with the same and the Féry radiation pyrometer.

4. Charles Engelhard, New York.
   American sales agent for the Heraeus LeChatelier platinum-rhodium thermo-couples probably the best upon the market. Also sells Siemens and Halske instruments for use in connection with temperature measurements. The Siemens portable galvanometer is one of the best made for thermo-electric work.

5. The Frink Pyrometer Company, Lancaster, Ohio.
   This concern manufactures both base metal and platinum couples together with indicating and recording instruments for use in connection with the same. The company has had considerable experience with pyrometric installations in clay products works.

6. Hoskins Manufacturing Co., Detroit, Mich.
Manufacturers of a general line of electric furnaces and of base metal couples. Also manufacturers of portable and switch board types of indicating instruments. No recording instrument is made by this company.

7. The Leeds and Northrup Co., Philadelphia.
Makers of a general line of resistance pyrometric apparatus. Can furnish both indicating and recording instruments.

8. Wilson-Maeulen Co., New York.
This company advertises base metal couples, platinum couples, portable and stationary indicating instruments and a recorder.